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Dated: 7 September 2001

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The Patent Office

01SEP00 E564915-1 D00393
P01/7700 0.00-0021370.2

Request for grant of a patent

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1. Your reference

2000P04846/GB/R76/MM/rr

2. Patent application number
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0021370.2

3. Full name, address and postcode of the or of each applicant *(underline all surnames)*

ROKE MANOR RESEARCH LIMITED

OLD SALISBURY LANE
ROMSEY
HAMPSHIRE, SO51 0ZN
UNITED KINGDOM

Patents ADP number *(if you know it)*

56154SS006

If the applicant is a corporate body, give the country/state of its incorporation

UNITED KINGDOM

4. Title of the invention

IMPROVEMENTS IN OR RELATING TO FLUID FLOW SENSORS

5. Name of your agent *(if you have one)*

DEREK ALLEN

"Address for service" in the United Kingdom to which all correspondence should be sent *(including the postcode)*

Siemens Shared Services Limited
Intellectual Property Department
Siemens House, Oldbury
Bracknell, Berkshire RG12 8FZ
United Kingdom

Patents ADP number *(if you know it)*

~~7761000002~~ 7396419002

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Country	Priority application number *(if you know it)*	Date of filing *(day / month / year)*

7. If this application is divided or otherwise derived from an earlier UK application, give the number and the filing date of the earlier application

Number of earlier application	Date of filing *(day / month / year)*

8. Is a statement of inventorship and of right to grant of a patent required in support of this request? *(Answer 'Yes' if:*
a) any applicant named in part 3 is not an inventor, or
b) there is an inventor who is not named as an applicant, or
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See note (d))

YES

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form	
Description	12
Claim *(s)*	2
Abstract	1
Drawing *(s)*	9

10. If you are also filing any of the following, state how many against each item.

Priority documents	
Translations of priority documents	
Statement of inventorship and right to grant of a patent *(Patents Form 7/77)*	1
Request for preliminary examination and search *(Patents Form 9/77)*	1
Request for substantive examination *(Patents Form 10/77)*	
Any other documents *(please specify)*	

11. I/We request the grant of a patent on the basis of this application.

Signature M D Mackett Date 31.08.2000

Margaret Mackett

12. Name and daytime telephone number of person to contact in the United Kingdom Margaret Mackett 01344 396808

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DUPLICATE

IMPROVEMENTS IN OR RELATING TO FLUID FLOW SENSORS

The present invention relates to improvements in or relating to fluid flow sensors, and is more particularly, although not exclusively, concerned with water flow sensors.

There are many different types of flow meter available on the market, with differing capabilities, in terms of technical performance, such as precision, accuracy, repeatability, capacity, flow direction sensitivity, sensitivity to fluid type, etc. However, all such meters are too complicated or, in any case, too expensive to be considered for use in a simple and inexpensive leak or flow detection system.

It is therefore an object of the present invention to provide a method using a simple flow meter or sensor which is relatively inexpensive.

In accordance with one aspect of the present invention, there is provided method of determining leakage from a fluid system comprising:- measuring data for the fluid at a point within the fluid system; and comparing the measured data with reference data, the system having a leakage when the measured data deviate from the reference data.

Advantageously, the measured data and the reference data comprise vibration data.

Preferably, the vibration data comprise vibration spectra.

The method further comprises attaching a sensor to the fluid system to obtain data therefrom indicative of fluid flow therethrough.

The sensor may include a piezo-electric material. Alternatively, the sensor may include a PVDF film.

The present invention is concerned with a novel method for monitoring the flow of fluids, typically water, in domestic or other pipe systems. The method of the present invention can be used in a system as disclosed in copending British Patent Application No. _________ entitled Improvements in or Relating to Leak Detection Systems (Our file reference 2000P04847) and filed concurrently herewith.

In accordance with the present invention, a flow meter or sensor has been designed to sell, as part of a leakage detection system, for a maximum of about £20. However, in order to achieve this price target, it is necessary to sacrifice to some degree such performance factors as accuracy, flow direction sensitivity, repeatability, and this has implications for the system in which the flow meter or sensor(s) is/are to be used.

For a better understanding of the present invention, reference will now be made, by way of example only, to the accompanying drawings in which:-

Figure 1 is a schematic block diagram of a flow meter or sensor arrangement for implementing the method of the present invention;

Figure 2 is a graph illustrating inlet pipe vibration spectra at various flow rates;

Figure 3 is a graph illustrating signal power against flow rate through a tap for various bandwidths;

Figure 4 is a graph illustrating signal power against flow rate through a tap for a bandwidth of 15 to 51kHz;

Figure 5 is a graph illustrating inlet pipe vibration spectrum history during a cistern refill;

Figure 6 illustrates spectra taken with four flow rates on a laboratory system;

Figure 7 illustrates the resulting power versus flow rate plots for various bandwidths on the laboratory system;

Figure 8 illustrates flow rate measurements over narrow bandwidths; and

Figure 9 illustrates the effect of a leak in a system.

Although the present invention will be described with reference to water in a domestic plumbing system, it will be appreciated that it is equally applicable to other fluid systems. The term 'fluid' herein is intended to encompass both liquids and gases.

In accordance with the present invention, a flow meter or sensor is utilised which makes use of the phenomenon of fluid flowing in pipes giving rise to acoustically- and seismically-coupled emissions. These emissions vary in amplitude and spectral content as the flow rate changes, and are affected, in varying degrees, by the size of pipe, what the pipe is made of, and by the presence of any bends or connections near to a point at which the emissions are measured.

Such a flow meter or sensor can be clipped or similarly attached to the pipe in which the measurement is to be made. Naturally, the pipe may have a diameter which ranges in size from a few millimetres (small) to up to hundreds of millimetres or perhaps bigger still (large).

The flow meter or sensor can be fabricated from piezo-electric material of various types, as is commonly used in accelerometers and other

vibration measurement components. Although sensors using piezo-electric materials are likely to be prime candidates for inexpensive flow meters, other seismic sensors can be considered for any particular application. For example, PVDF films may also be of use in some circumstances, as well as other strain gauges, geophones and/or hydrophones.

In Figure 1, a portion of a pipe 10 is shown. A sensor 12 is simply clipped to the pipe 10 at a measurement position, for example, using, a Jubilee clip or similar device. Some coupling paste or wax (not shown) is applied to the sensor 12 to enhance the contact with the pipe 10. Readings taken by the sensor 12 are sent to a processing unit 14 which may be located adjacent the sensor 12 or may be remote therefrom.

If the processing unit 14 is remote from the sensor 12, the sensor 12 may include an electronic pre-amplifier/buffer 16 for boosting the signal from the sensor 12 for transmission to the processing unit 14. The sensor 12 may be connected to the processing unit 14 by means of a wired connection 18 as shown in Figure 1. Alternatively, signals from the sensor 12 may be transmitted by radio or other medium to the processing unit 14. Also, included in the sensor 12 is a power pack 20 for providing the necessary power for its operation. Naturally, various other means of powering the sensor 12 may be used, for example, remote powering, extracting power from the pipe flow or coupling the sensor 12 to the mains electricity supply.

Experiments were carried out on a domestic plumbing system to indicate the basis of operation of a sensor in accordance with the present invention. The plumbing system used consisted of 15mm outside-diameter, soldered copper piping. Vibration measurements were taken at a

point on an inlet pipe to the system close to the main stopcock as water flowed from a tap some 2.5m away from the main stopcock. There were no other flows in the system whilst these measurements were taken.

An accelerometer was fixed onto the wall of the inlet pipe with a thin layer of special wax, and was oriented to measure the radial motion of the wall. A small, light accelerometer was used, which would not greatly influence the motion of the pipe. Different flow rates were used and vibration spectra obtained are shown in Figure 2.

Figure 2 illustrates the relative magnitude of acceleration against frequency for five different flow rates and Table 1 below gives the relationship between the lines and the flow rate.

Table 1.

Curve no.	1	2	3	4	5
Flow rate (l/min)	11.6	3.8	0.94	0.27	0.07

As can be seen from Figure 2, at higher flow rates, strong vibration is measured over a wide range of frequencies. The vibration spectra have many peaks and troughs, and this structure does not vary much with flow rate. However, the vibration level increases strongly with flow rate at all frequencies.

Below a flow rate of about 0.07l/min (curve 5), there are no detectable pipe vibrations above the fairly flat noise level. With a flow rate of 0.27l/min (curve 4), there is a detectable vibration. The minimum detectable flow rate thus lies somewhere between 0.07 and 0.27l/min, for this particular configuration of water pipes and vibration sensor.

However, it will be appreciated that the data shown in Figure 2 is system related, and will vary from system to system. The data will also vary for different sensors in the same system.

A system of soldered or compression-jointed copper pipes would be expected to have many resonances and anti-resonances, which might explain the many peaks and troughs in the measured spectra. The attenuation of the piping would also be expected to increase with frequency, and this is borne out by measurements made with an outlet some 15m away from the measurement point, where the spectral energy falls off at much lower frequencies and the shape of the spectra is different.

The vibrations are likely to be generated not by the flow in the inlet pipe but by flow through the outlet tap or other orifice. They are then transmitted, as sound in the water and/or pipe vibrations, to the inlet pipe. The transmission characteristics of the pipe network will thus have a strong influence on the vibration picked up at the sensor position.

The foregoing suggests that a seismic sensor will not measure just local-flow and the vibrations it senses could arise anywhere on the piping network. The distance over which this can be achieved will depend on the frequency band being examined, and this attribute could be used to distinguish between flows which are near to or further away from the position of the sensor.

From the results for flows through the tap as illustrated in Figure 2, curves showing signal power versus flow rate have been produced for a number of different frequency bandwidths as shown in Figure 3. The signal response from the sensor was integrated over various frequency bandwidths as shown in Table 2 below.

Table 2.

Curve no.	21	22	23	24	25
Bandwidth (kHz)	0-51.2	1-15	15-51	22-28	38-42

As shown in Figure 3, if a bandwidth from 15kHz to 51kHz is chosen (curve 23), an almost linear relationship results. Wider bandwidths, extending downwards to frequencies below about 10kHz, enhance the high flow rate signal but make the response far from linear.

The 15kHz to 51kHz bandwidth curve is reproduced alone in Figure 4. A continuous curve 20 is used to joins up five measured points 42, 44, 46, 48, 50 (using a smoothing function), and a straight line fit to this is shown by dotted line 52. For example, point 44 can be considered as relating to a dripping tap. Pouring a glass of water has a flow rate of around 10l/min and running a bath or having a garden sprinkler on has a flow rate of around 20l/min.

The minimum flow rate that can be measured before the response becomes non-linear (perhaps due to the domination of noise) is approximately 0.2l/min, although this is obviously subject to confirmation when more accurate and comprehensive measurements can be made.

Examining the range of flow rates likely to be experienced in the domestic environment, the estimates given in Table 4 below may be obtained. Also included in Table 4 are the estimated liminal flow rates, and the rate corresponding to a dripping tap, to scope the range of flow rates that might be experienced. Some examples of these flow rates are included in Figure 4 for comparison.

Table 3.

Function	**Estimated Peak Flow Rate (l/min)**	**Integrated Flow (l)**
Bath being run	20	140
Lawn sprinkler	20	-
Basin being filled	20	5
Glass of water being filled	10	0.3
Liminal flow rate	0.2	-
Leakage (dripping)	<0.005	-

Although the best fit straight line is shown extrapolated up to a flow rate of 20l/min, subsequent measurements have shown that this should not be assumed.

In order to establish a more general position, a laboratory system was prepared and measurements taken which indicate features which are not evident from the foregoing measurements. These measurements are illustrated in Figure 6.

In Figure 6, the relationship between relative magnitude of acceleration and frequency is shown for four flow rates as indicated by curves 60, 62, 64, 66. Curve 60 corresponds to a flow rate of 20l/min, curve 62 to a flow rate of 16l/min, curve 64 to a flow rate of 10l/min and curve 66 to a flow rate of 4l/min. These flow rates extend into a higher flow range than that illustrated in Figure 2, that is, up to 20l/min instead of 12l/min. These measurements therefore cover flow rates up to the maximum likely in a domestic situation, but were limited at the lower end by the measuring apparatus to 4l/min.

It is to be noted that the curves shown in Figure 6 are rather different to those in Figure 2 and that the ordinate axis is not related to an absolute measure of power and is therefore not necessarily comparable with that of Figure 2.

Figure 7 illustrates the relationship between integrated power and flow rate for bandwidth measurements. The curves 70, 72, 74, 76, 78 correspond to respective bandwidths as shown in Table 4 below.

Table 4.

Curve	70	72	74	76	78
Bandwidth (kHz)	0 - 51.2	0.256 - 51.2	15.1 - 51.2	15.1 - 30	0 - 15.1

As can be seen in Figure 7, the main factor which has been identified from the measurements is that the relative magnitude of the sensor output does not climb monotonically with increasing flow rate, but reaches a peak and then decays again for higher flow rates. The turning point for the laboratory system occurs at around 10l/min for wide bandwidth measurements, which is in line with the maximum flow rate obtained previously. A further observation is that, for the laboratory system, the results in the lower flow regime are not linearly related to flow rate.

It is believed, however, that both sets of results are experimentally valid. Apart from the non-linearity, the main issue for consideration is the falling away of the output at higher flow rates.

A study was made of integrated power in different frequency regimes and the results obtained are shown in Figure 8. Here, curve 80

corresponds to a bandwidth of 0 to 51.2kHz, curve 82 to a bandwidth of 10 to 12kHz and curve 84 to a bandwidth of 0 to 2kHz, the bandwidth of curves 82 and 84 falling within the bandwidth of curve 80. It can readily be seen that the integrated power over the entire frequency range peaks around 10l/min (curve 80), but when bandpassing the frequency ranges as shown by curves 82 and 84, the peak can be seen to be shifted.

Boxes 86, 88 indicate regions of the complete frequency range measurement where a narrow band measurement could be used to resolve ambiguities in the estimation of the flow rate. The principle is as follows: a set of measurements is made in three frequency bands, and the outputs compared and thresholded. With suitable calibration, the relative amplitudes in each band provide an unambiguous output of flow rate and may aid in achieving high repeatability and accuracy.

Thus, a simple vibration sensor should be able to measure flows from a usefully low level up to mid-ranges of flow rate. In some circumstances, the response of this regime may be linear, and in others non-linear.

It is believed that such a sensor could not measure the flow from a dripping tap. However, these leaks are seldom a significant problem in relation to the kind of design requirements for which it has been developed – protecting against damage to the house, or the cost of losing substantial amounts of water.

Similar measurements to those made at a point around 2.5m from an outlet, in this case a tap, were also made 15m away from an outlet. It was found that the spectral energy falls off at much lower frequencies and the shape of the spectra is different. In this latter case, the outlet was a

cistern refilling after being flushed. Twenty spectra were recorded, the first immediately after the ball valve opened, that is, when the cistern was flushed, and the remainder at three-second intervals thereafter. The sequence of acceleration spectra measured on the inlet pipe in this case is shown in Figure 5.

As in the short range measurements, that is, at around 2.5m, strong vibration was measured over a wide range of frequencies during the high initial flow rates. The vibration level decreased steadily over time, as the flow rate fell, although the structure of peaks and troughs in the vibration spectrum remained fairly constant. Actual flow rates were not available for these measurements. Note that these spectra have half the frequency span of the spectra in Figure 2.

Observations of this process suggest that the flow into the cistern after emptying is approximately constant during the main filling period of about 70 seconds. Another 20 seconds is then needed to fill the cistern completely, during which period the flow rate reduces. So, for the period recorded, of 60 seconds, one would expect the flow to be fairly constant.

The inlet pipe vibration spectra measured with outflow into the cistern are very different from those measured with outflow through a tap, although this may well be because of the much greater distance from the measurement point to the orifice or outlet rather than the type of valve. The pattern of peaks and troughs is different, and there is no detectable vibration at frequencies above about 15kHz, whereas the tap vibration spectra extend up to 50kHz.

A conclusion may be reached, tentatively, that (i) the much longer range from the source to the sensor has made the measurement process

very insensitive, and (ii) a rather different sound generation process may be occurring with the cistern flow. In fact, the poor performance at long ranges is an advantage to the use of such sensors in a practical architecture, in that it will enable several sensors to be placed throughout the system and to function largely independently of each other, assuming higher frequency signals are selected and the low frequency energy is rejected.

However, the object of the present invention is to be able to detect the presence of leaks rather than flows through taps and valves. Measurements were taken of a pipe with water flowing out of a tap. A small puncture was then inserted in a pipe to simulate the presence of a leak. Further measurements were taken of the same pipe with water flowing out of the tap. The results obtained are shown in Figure 9.

In Figure 9, curve 90 illustrates the flow through the tap without the simulated leak, curve 92 illustrates the flow through the tap with the simulated leak, and curve 94 illustrates the leak flow with the tap turned off. It can be seen that, over a range of frequencies from about 6kHz up to 50kHz, a much stronger signal is emitted by the leak – but only if the tap is not turned on. This suggests that smaller flows characterised by leaks will provide characteristic signals that can be used by a fairly simple processor to determine the type of water flow that is being measured and propose the kind of response appropriate to such flows, for example, leakage, inadvertent flow, intended flows etc.

Although the method of the present invention has been described with reference to water flow, it will readily be appreciated that the present invention may be used for measuring vibration caused by the flow of other fluids through a system similar to that of a domestic plumbing system.

CLAIMS:

1. A method of determining the presence of a leakage from a fluid system by sensing the vibrations induced by passage of the fluid through the leakage.

2. A method of determining leakage from a fluid system comprising:-

measuring data for the fluid at a point within the fluid system; and

comparing the measured data with reference data, the system having a leakage when the measured data deviate from the reference data.

3. A method according to claim 2, wherein the measured data and the reference data comprise vibration data.

4. A method according to claim 3, wherein the vibration data comprise vibration spectra.

5. A method according to any one of claims 2 to 4, further comprising attaching a sensor to the fluid system to obtain data therefrom indicative of fluid flow therethrough.

6. A method according to claim 5, wherein the sensor includes a piezo-electric material.

7. A method according to claim 5, wherein the sensor includes a PVDF film.

8. A method according to claim 5, wherein the sensor comprises one of a strain gauge, geophone or hydrophone.

9. A method of determining leakage from a fluid system substantially as hereinbefore described with reference to the accompanying drawings.

ABSTRACT

IMPROVEMENTS IN OR RELATING TO FLUID FLOW SENSORS

Described herein is a method for determining the presence of a leakage in a fluid system, for example, a domestic plumbing system. The method comprises measuring vibration spectra relating to fluid flow in the system and comparing the measured spectra with reference spectra to determine the presence of a leakage. A simple sensor (12) is attached to a pipe (10) for measuring the vibration and is connected to a processing unit (14) via wired connection (18). The sensor (12) may also be provided with an amplifier/buffer (16) and a battery pack (20).

(Fig. 1)

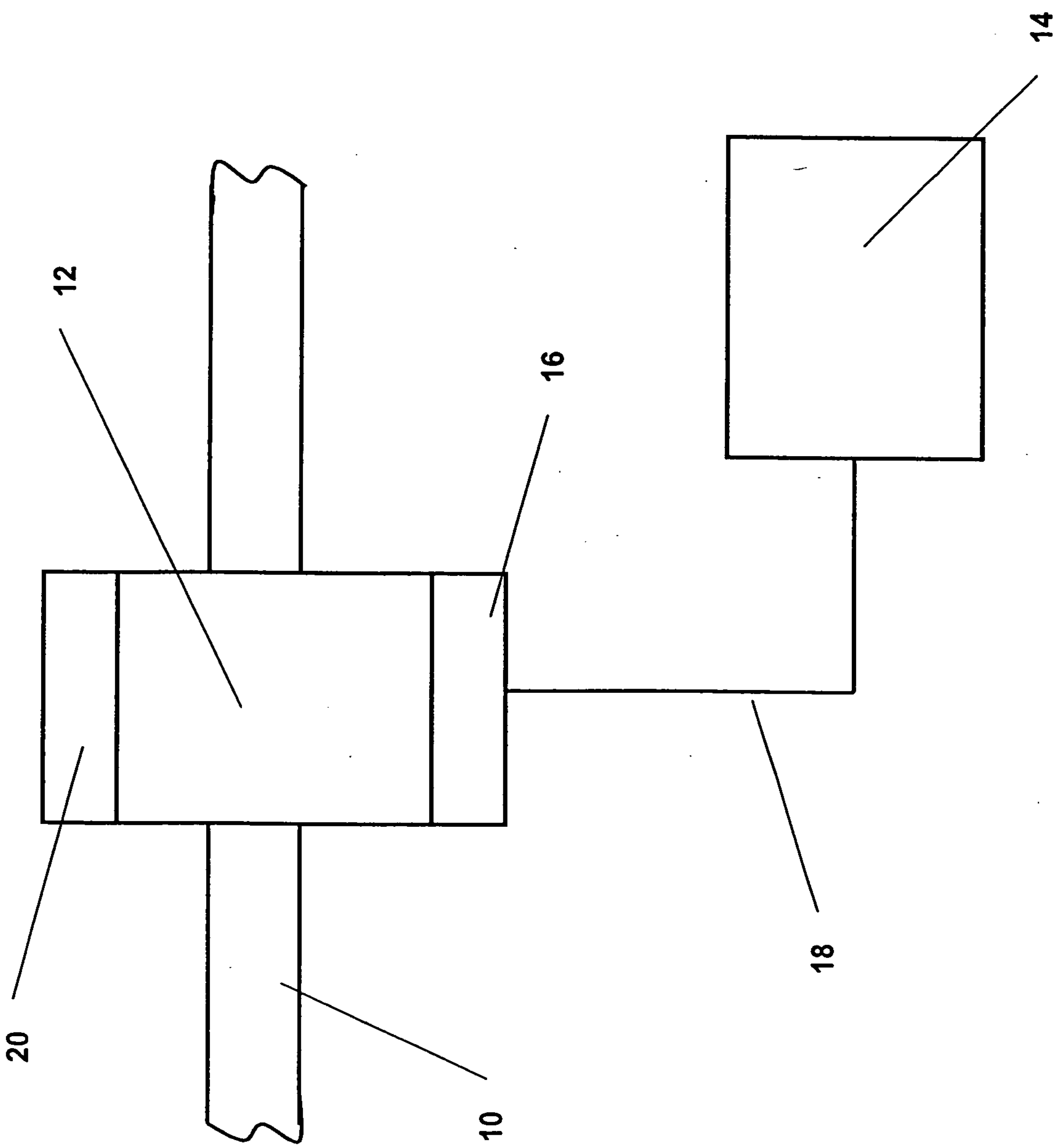


Fig. 1

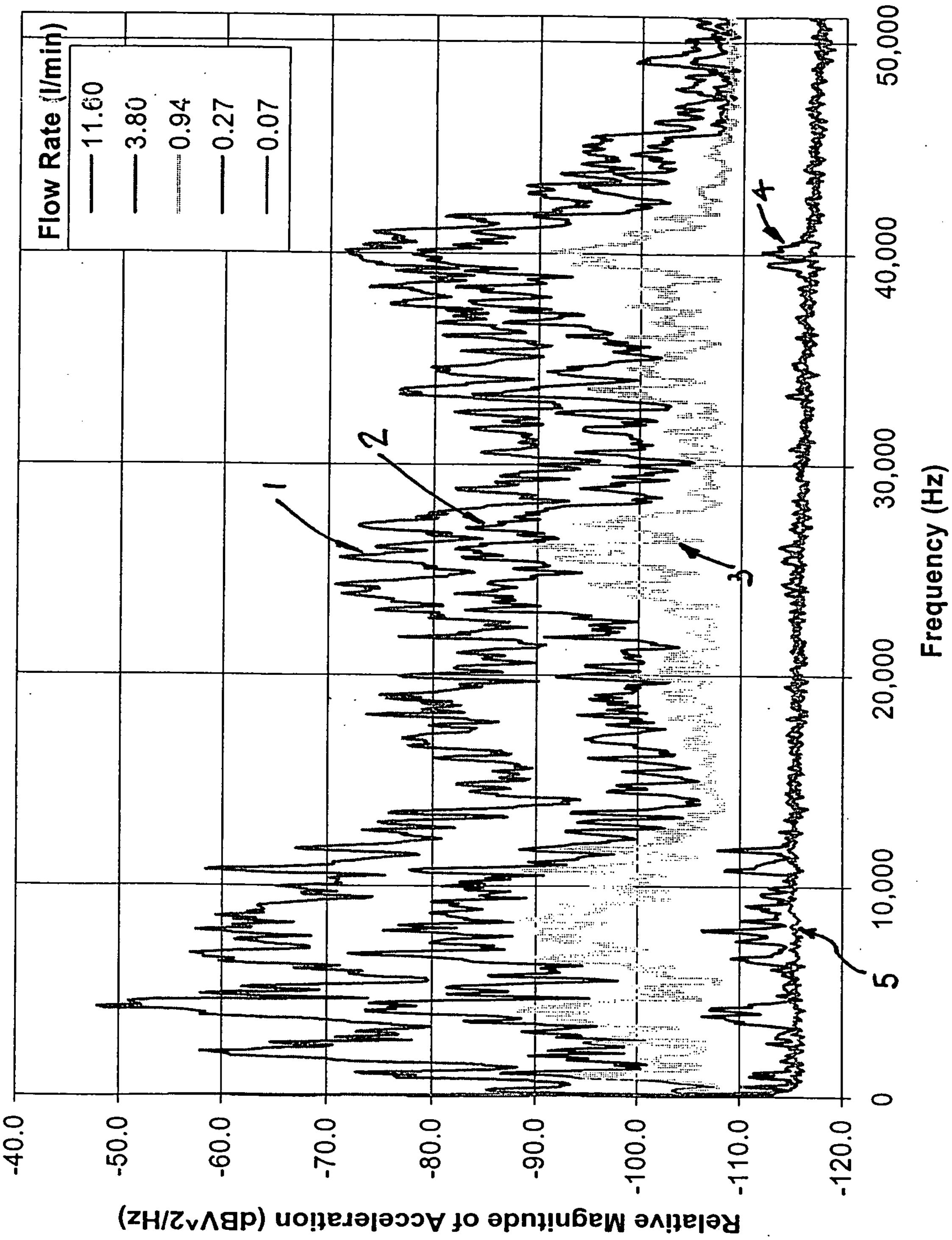

Flow Rate (l/min)
11.60
3.80
0.94
0.27
0.07
Relative Magnitude of Acceleration (dBV^2/Hz)
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
-110.0
-120.0
Frequency (Hz)
0
10,000
20,000
30,000
40,000
50,000
1
2
3
4
5

Fig. 2

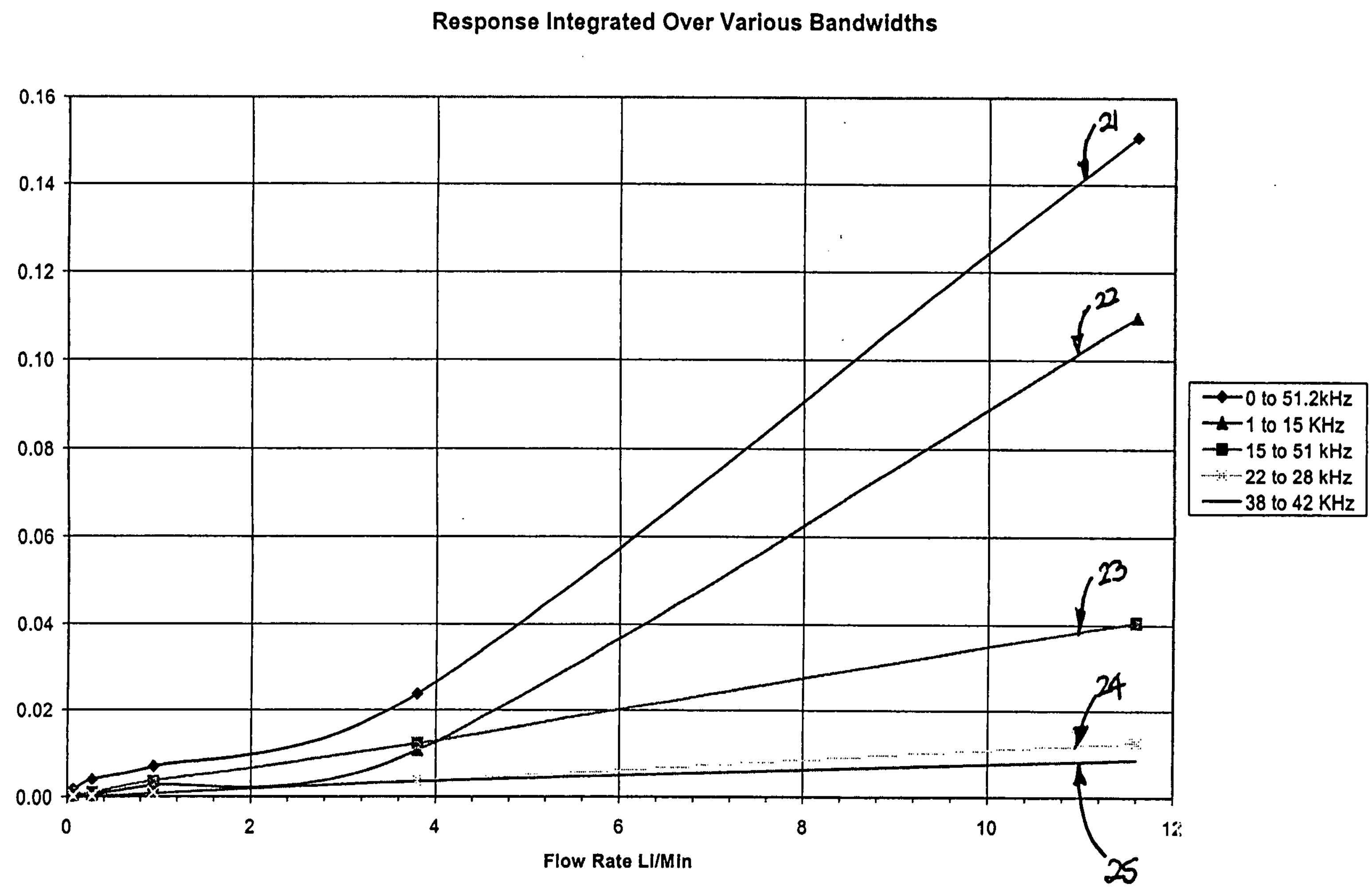

Response Integrated Over Various Bandwidths
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
2
4
6
8
10
12
Flow Rate Ll/Min
0 to 51.2kHz
1 to 15 KHz
15 to 51 kHz
22 to 28 kHz
38 to 42 KHz
21
22
23
24
25

Fig. 3

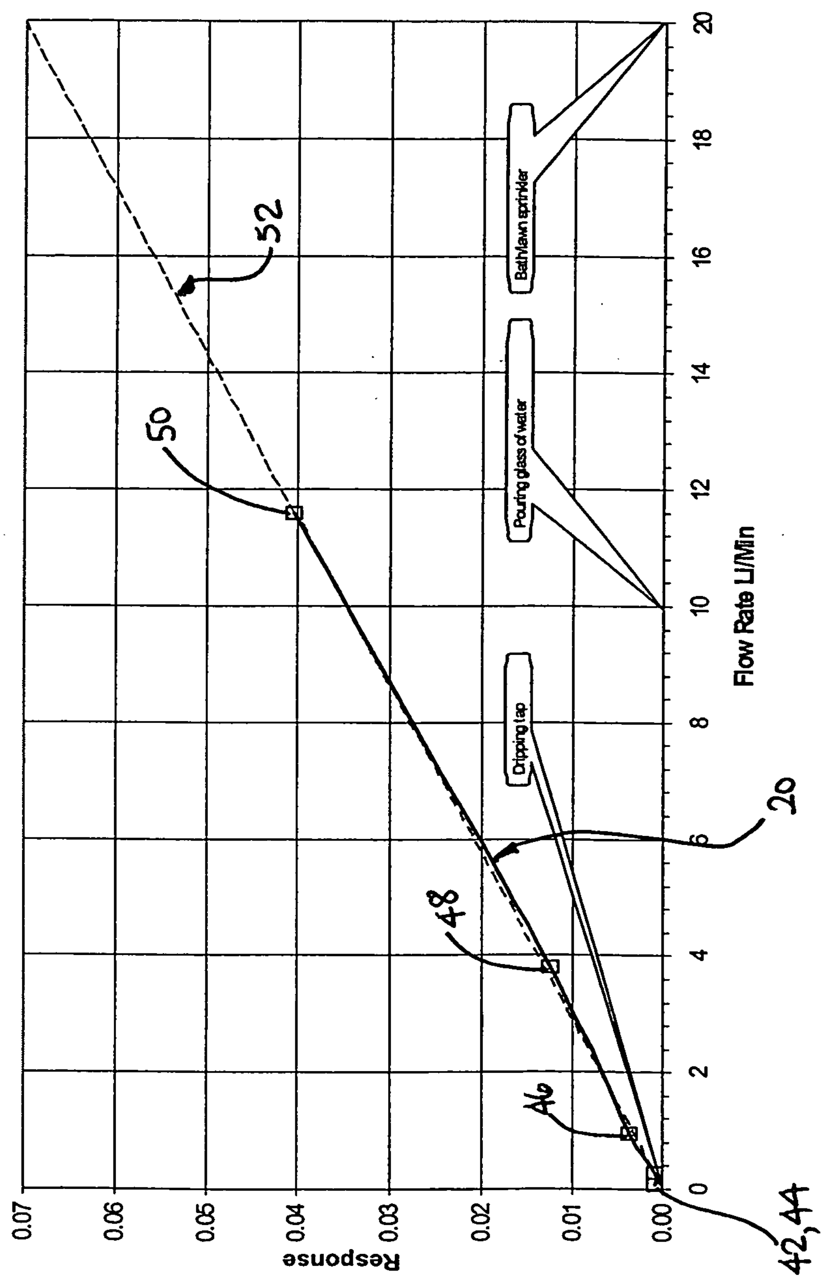
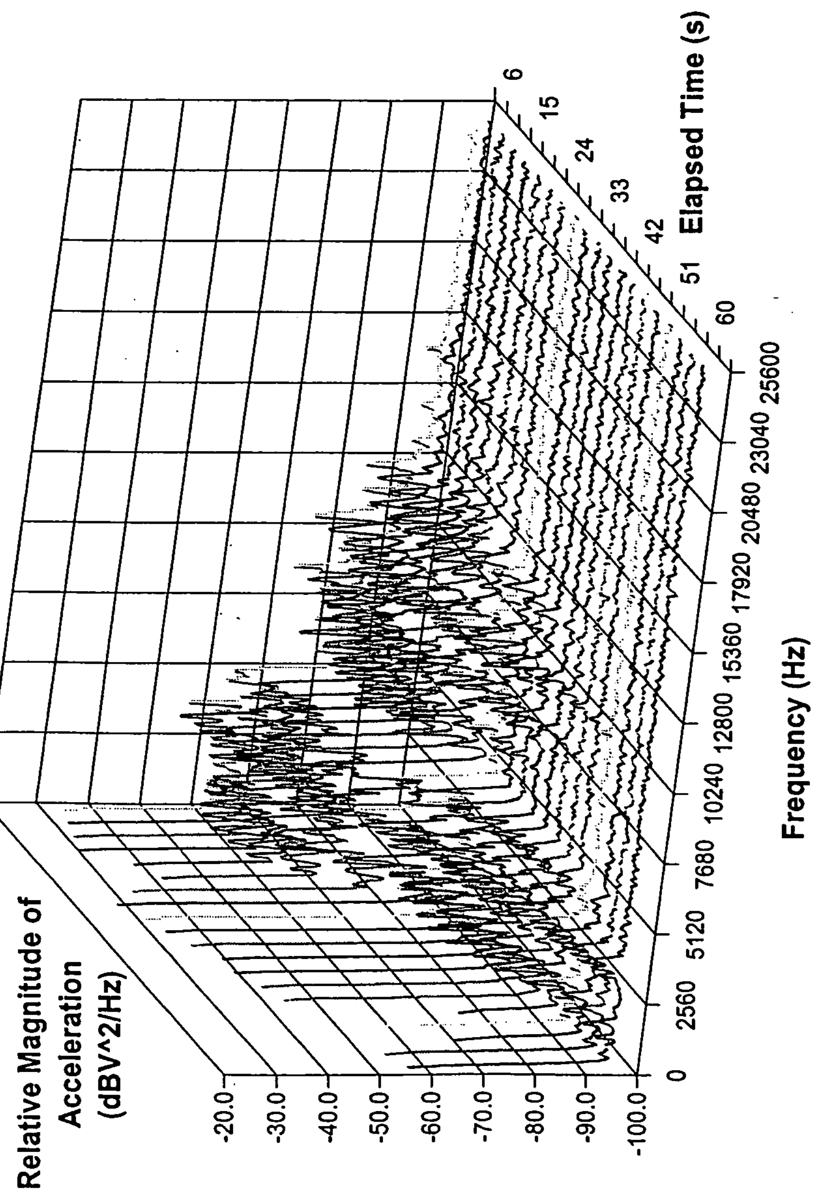

Response
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0
2
4
6
8
10
12
14
16
18
20
Flow Rate Lt/Min
Bath/lawn sprinkler
Pouring glass of water
Dripping tap
52
50
48
46
20
42,44

Fig. 4



Relative Magnitude of Acceleration (dBV^2/Hz)
-20.0
-30.0
-40.0
-50.0
-60.0
-70.0
-80.0
-90.0
-100.0
0
2560
5120
7680
10240
12800
15360
17920
20480
23040
25600
Frequency (Hz)
6
15
24
33
42
51
60
Elapsed Time (s)

Fig. 5

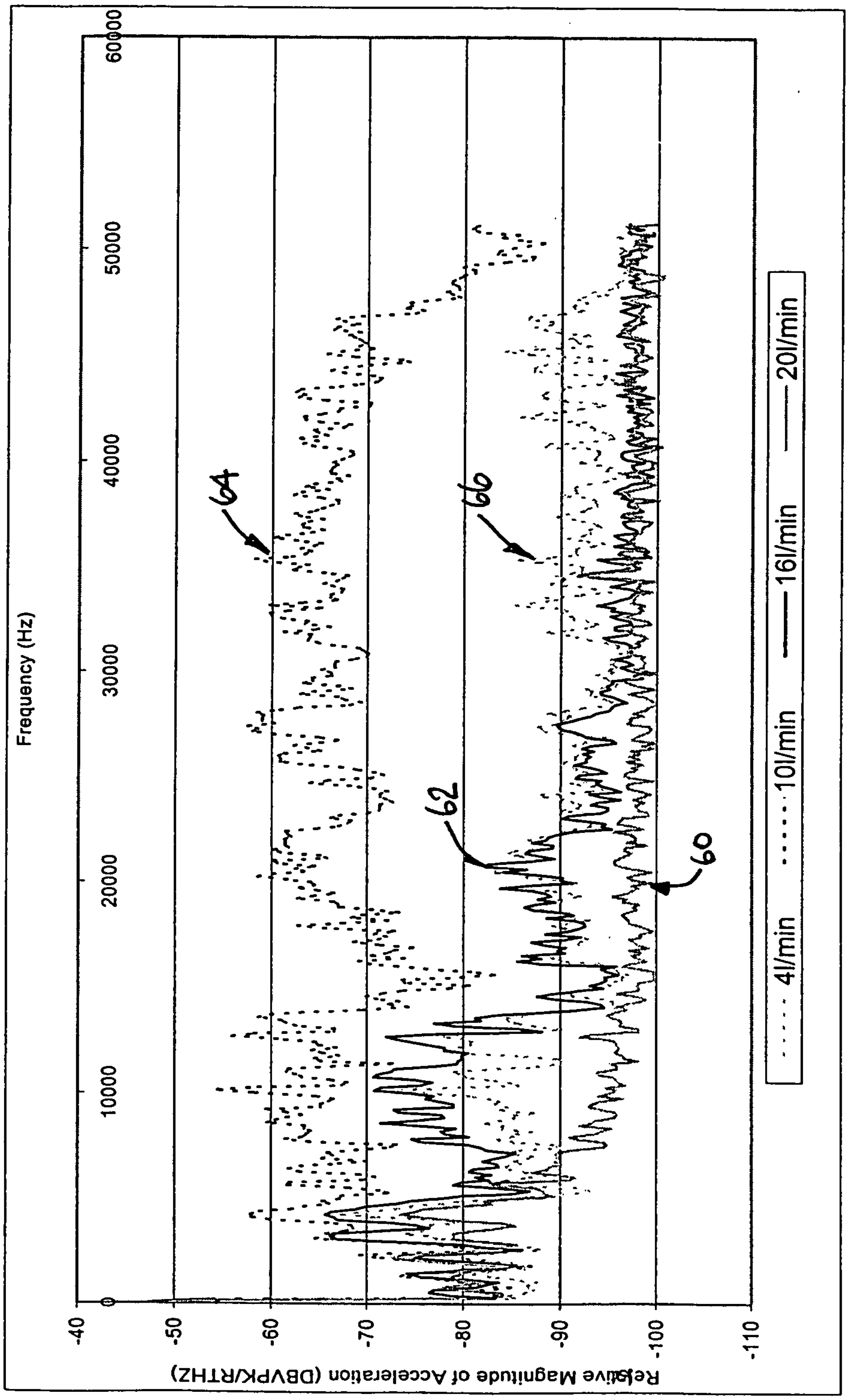
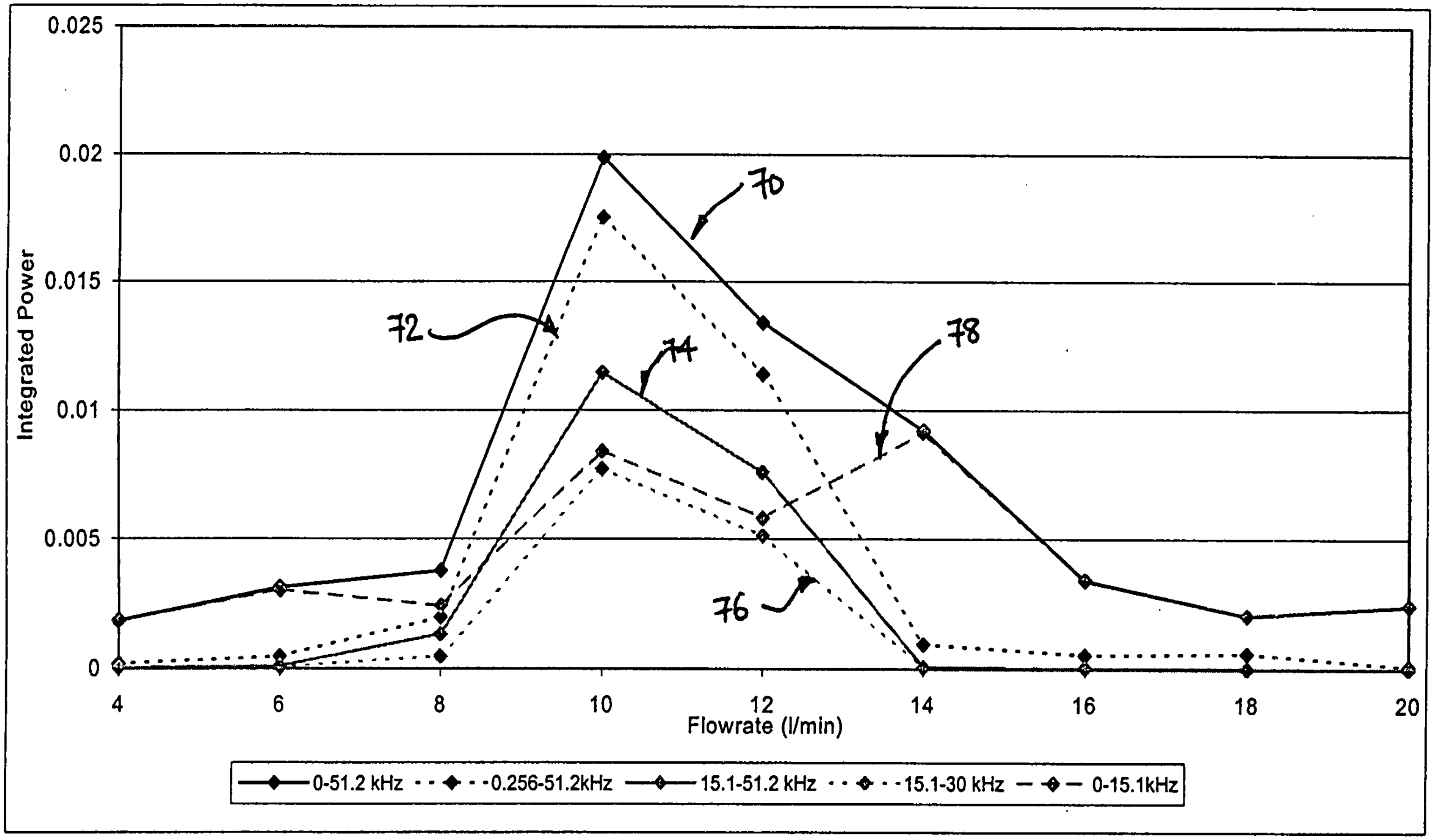

Frequency (Hz)
0
10000
20000
30000
40000
50000
60000
Relative Magnitude of Acceleration (DBVPK/RTHZ)
-40
-50
-60
-70
-80
-90
-100
-110
64
66
62
60
4l/min
10l/min
16l/min
20l/min

Fig. 6



Integrated Power
0.025
0.02
0.015
0.01
0.005
0
4
6
8
10
12
14
16
18
20
Flowrate (l/min)
0-51.2 kHz
0.256-51.2kHz
15.1-51.2 kHz
15.1-30 kHz
0-15.1kHz
70
72
74
76
78

Fig. 7

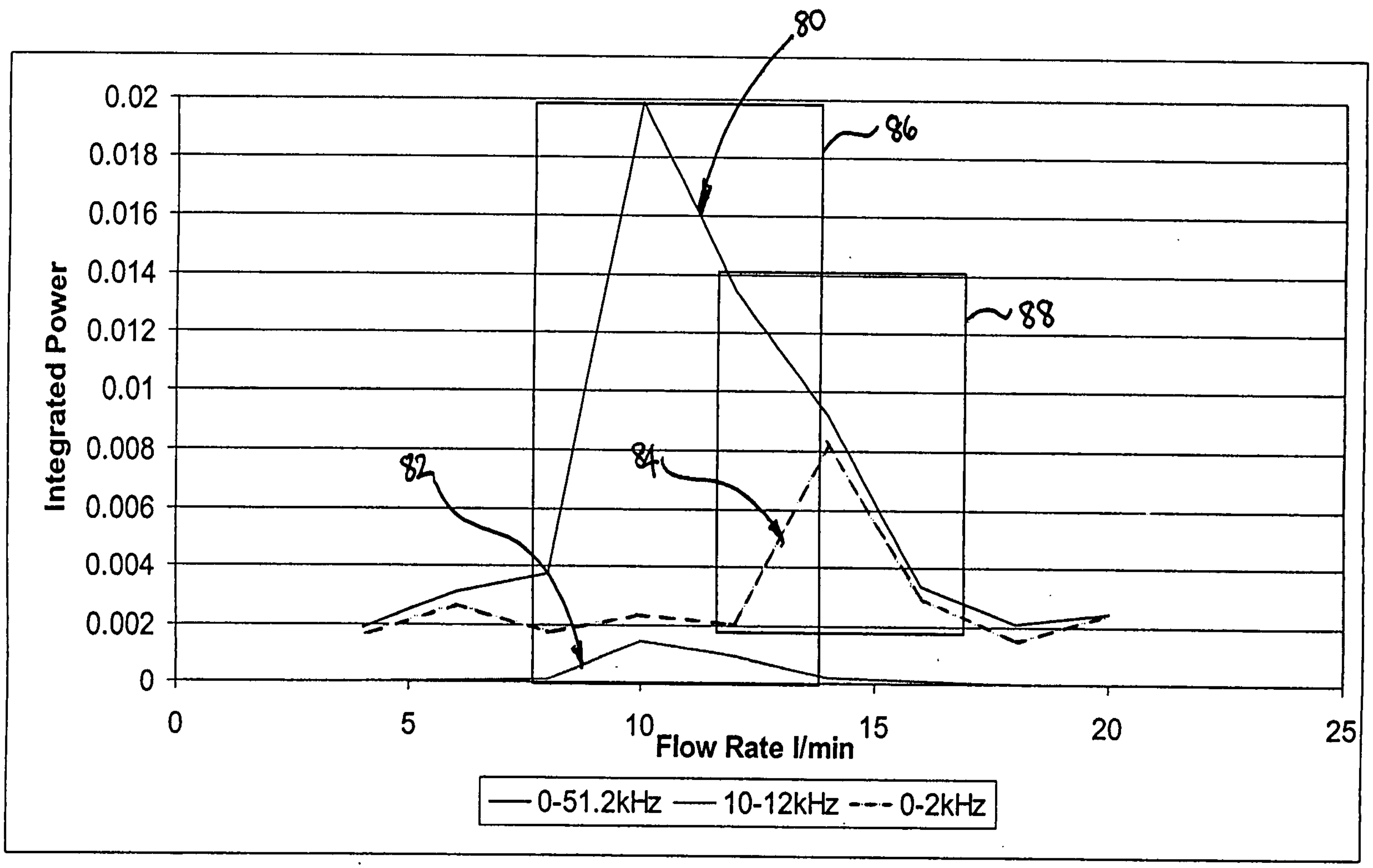
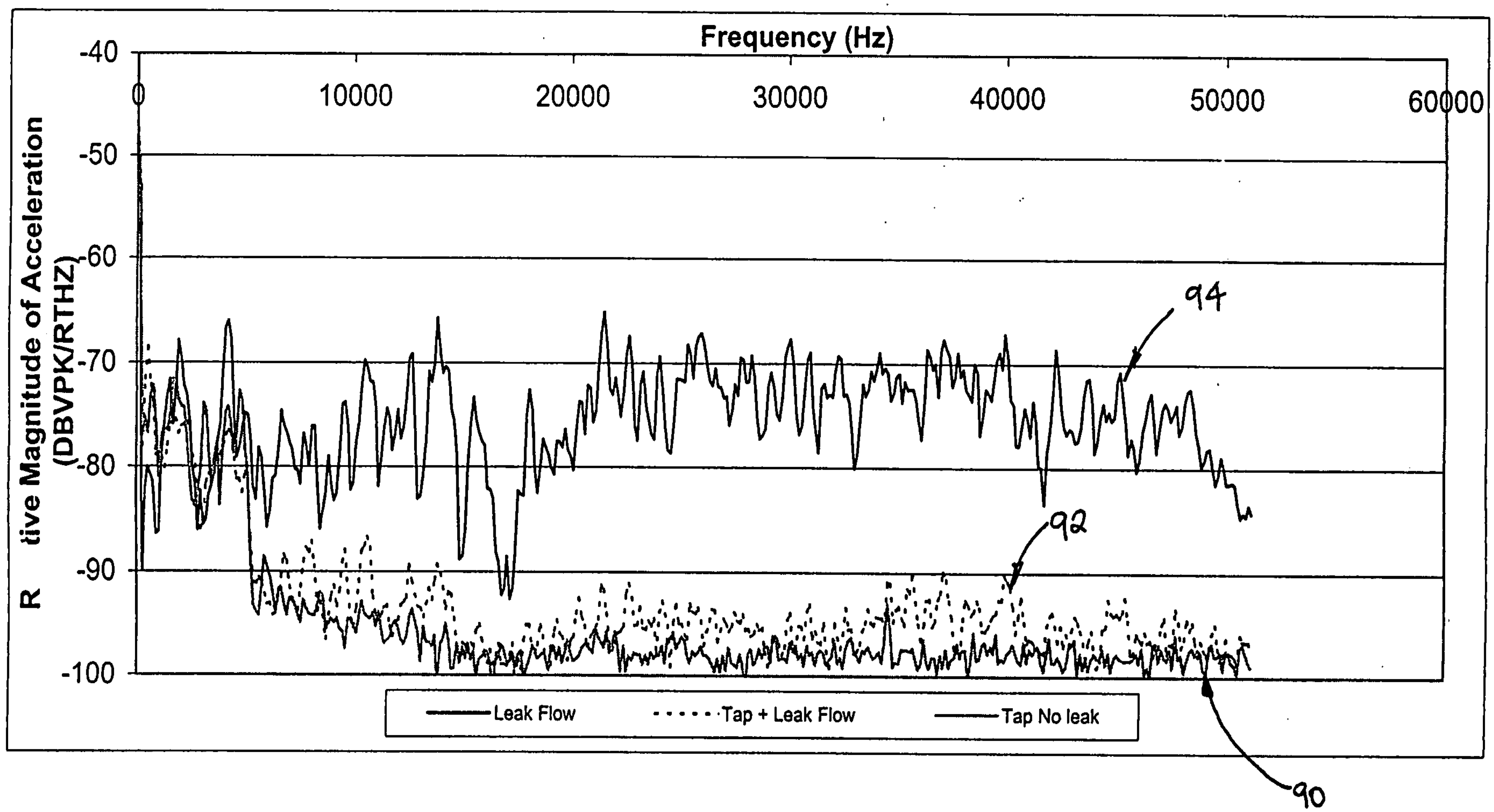

Integrated Power
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
5
10
15
20
25
Flow Rate l/min
0-51.2kHz
10-12kHz
0-2kHz
80
82
84
86
88

Fig. 8



Frequency (Hz)
R tive Magnitude of Acceleration (DBVPK/RTHZ)
-40
-50
-60
-70
-80
-90
-100
0
10000
20000
30000
40000
50000
60000
94
92
90
Leak Flow
Tap + Leak Flow
Tap No leak

Fig. 9